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THE EFFECT OF DEHYDRATION AND HYPERTHERMIA ON THE HOMEOSTASIS OF THE HEALTHY MAN

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Many infectious diseases of the gastrointestinal tract, including acute /27* gastroenteritis, cause dehydration and change in the body temperature. The regulation of disorders of the homeostasis during dehydration and hyperthermia is of interest for pathogenetic founding of a method of treating patients with infectious diseases of the digestive organs (V. N. Nikiforov et al.; T. A. Medne; M. F. Kuz'min; Yu. Ye. Vel'tishchev, etc.).

Modern clinical and physiological methods of investigation enable one simultaneously to study the condition of the water-salt metabolism, the acid base equilibrium, the movement of electrolytes, the physical chemical properties and coagulating activity of the blood, hormonal influences, external and tissue respiration, circulation in the large and small circuit. These data are of important significance for selecting facilities and tactics of treating the infected patient (V. I. Pokrovskiy and T. M. Guseva). It has been shown that a vital condition of employing medical techniques in the clinic is comparing obtained data with the norm — a control group of healthy people. The results of such clinical and physiological investigations of the influence of dehydration and hyperthermia on the human organism are described inadequately in the literature.

Twenty healthy men ranging in age from 18 to 32 were investigated; with the goal of dehydration and increasing the body temperature, a Finnish sauna in the /28

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*Numbers in the margin indicate pagination in the foreign text.

modification of P. P. Belousov was employed (temperature in the sauna — 80 to 100°, humidity up to 8%).

In 14 of the 20 subjects (first group), after a 4 to 7 stay regime in the sauna of 15 to 30 minutes per stay, weight loss comprised 2.2 to 3.7% of the original level (on the average 2.80 ± 0.09%). Persons of the first group felt well, and were investigated 2 hours after the sauna at normal body temperature (up to 37°). In the remaining 6 people (second group), after a 35 to 55 minute stay in the sauna, body temperature increased, on the average, to 39.1° (from 38.1 to 40.3°), they felt worse, and tachycardia, dyspnea, sensations of discomfort and headache appeared. The second group was investigated immediately after leaving the sauna; weight loss on the average was 1.5 ± 0.20 kg. The difference between the first group and the second group was statistically reliable ($P < 0.05$). Hence, the first group was investigated in a condition of physiological dehydration at normal body temperature, while the second group was investigated at increased body temperature and less fluid loss than in the first group.

The method of investigating the first and second groups both before and after the sauna included simultaneous determination of the acid base balance, physiochemical properties of the blood and plasma, coagulating factors of the blood, movement of electrolytes of the blood and urine, the functional condition of the heart and peripheral circulation in the large and small circuit.

The condition of the acid base equilibrium in the arterial and venous blood (pH, PCO_2, PO_2, SB, BE) were determined on the Astrup apparatus, the hematocrit index on the Adams centrifuge, the physiochemical properties (specific gravity of blood and plasma, content of total protein) after the method of Slyke and Phillips, viscosity of the blood — on the VK-4 viscosimeter, change in the coagulating activity of the blood (phase of coagulation and maximum amplitude) on the TROMB-1 apparatus.

Saturation of the arterial and venous blood with oxygen (in %) was established on the 057-M cuvette oxyhemometer, content of carbon dioxide in the expired air (in %) on the GUKh-2 gas analyzer, bleeding time (in seconds), in the lungs-ear region were determined on the 036-M oxyhemograph.

Movement of electrolytes of the blood (plasma, potassium and sodium, and erythrocytes) and of the urine were investigated on the Zeiss-III flame photometer; the content of chlorine in the plasma was determined by the Schales method.

The condition of the contractive activity of the heart was estimated by the data of the polycardiogram (PCG). The LKAR-6 apparatus was used to simultaneously record the electrocardiogram from 12 leads, the SFG of the carotid and brachial arteries, the FKG from the apex of the heart and the BKG of displacement. The rate of propagation of the arterial wave and phases of the cardiac activity were calculated (in each cycle and for one minute). The arterial pressure was recorded on the PCh-2 apparatus, and the venous pressure by direct measurement. Change in the size of the heart (lateral, diagonal and length dimensions in mm) was determined in direct projection on the 12 P-5 apparatus with the subject lying on his back. The results of the investigation were subjected to statistical processing.

The investigation of the physiochemical properties of the blood in dehydration of the blood (first group) showed a statistically reliable increase in the specific gravity of the blood (from 1056.7 ± 0.64 to 1060.36 ± 0.67; $P < 0.01$), plasma (from 1024.4 ± 0.35 to 1026.8 ± 0.32; $P < 0.05$), and content of total protein (from 6.67 ± 0.99 to 7.21 ± 0.10 g%; $P < 0.01$); and there was an increase in the viscosity of the blood from 4.8 ± 0.17 to 5.8 ± 0.58 units ($P < 0.05$). These data indicate thickening of the blood as the result of fluid loss in the sauna (sweating). The fact that the hematocrit index here increased in a statistically unreliable fashion from 43.8 ± 0.71 to 45.0 ± 0.8), indicates a compensative displacement of the extracellular fluid to the vascular tree as the result of an increased difference in the osmotic pressure of the media.

Thickening of the blood in dehydration of the first group did not have a significant effect on the condition of blood coagulation. Thus, according to the data of the thromboelastogram (TEG), the time of formation of thromboplastin and thrombin – the R index (I and II phases of coagulation) change in comparison with the control in a statistically unreliable fashion. The K_1 index (time of clot formation – onset of III phase of coagulation), increased from 4.4 ± 0.15 to 5.1 ± 0.21 seconds ($P < 0.05$), while the maximum amplitude

on the other hand, decreased from 6.1 ± 0.07 to 5.1 ± 0.003 cm ($P < 0.01$). The difference in changes of PEG from the control condition did not exceed the limits of physiological fluctuations observed by Hartert in healthy people. /29

The influence of hyperthermia on change in the physiochemical properties of the blood and PEG in the second group did not differ from that in the first group.

The electrolyte balance and dehydration (first group) changed in comparison with the control condition in a statistically unreliable fashion. An exception was a decrease in the concentration of plasma chlorine from 88.0 ± 1.4 to 83.3 ± 1.5 meq/ℓ ($P < 0.05$), and an increase in the content of potassium in the urine, from 23.0 ± 1.3 to 28.9 ± 1.7 meq/ℓ ($P < 0.05$).

In hyperthermia (second group), the concentration of sodium in the plasma and erythrocytes increased in a statistically unreliable fashion (respectively, from 186.8 ± 6.9 meq/ℓ and from 17.5 ± 0.44 to 21.7 ± 2.20 meq/ℓ). However, the predominant increase in the level of sodium was expressed in an increase of Na/K plasma index from 38.9 ± 1.3 to 44.82 ± 2.27 ($P < 0.05$) and by a decrease in the K/Na ratio of the erythrocytes, from 4.21 ± 0.15 to 3.01 ± 0.41. There is a decrease in the content of plasma chlorine (to 74.5 ± 3.6 meq/ℓ; $P < 0.01$) which exceeded that in the first group in comparison with the control level.

On the whole, the change in potassium and sodium indicated that among healthy people in hyperthermia, the balance of electrolytes changes as the result of a predominance of sodium (relative hypokalemia), with physiological dehydration the balance of potassium and sodium remains unchanged. The content of chlorine in the plasma decrease in a statistically reliable fashion in both groups, but particularly in the second group.

The difference in the contractile activity of the heart and the condition of the peripheral circulation attracted attention; this difference was indicated by the electro-, polycardio-, oxygeno-, and x-ray recordings, as well as by the arterial and venous blood pressure.

In dehydration (first group), the maximum arterial pressure decreased from 128.6 ± 3.29 to 117.0 ± 3.28 mm Hg ($P < 0.05$), while the venous decreased from 85.6 ± 7.5 to 59.7 ± 11.8 mm water column ($P < 0.05$). The blood flow slowed: the time of blood flow in the region from the lungs to the ear increased from 4.42 ± 0.05 to 5.9 ± 0.09 seconds ($P < 0.01$). The number of cardiac contractions, the duration of the diastole and other data of the PKG did not differ from the control condition.

In hyperthermia (second group), the arterial pressure did not differ from the control level ($P > 0.05$), while venous pressure increased from 85.6 ± 7.5 to 93.65 ± 21.2 mm water column ($P < 0.05$), there was accelerated blood flow (time of blood flow in the region from the lungs to the ear decreased in comparison with the control from 4.42 ± 0.05 to 3.3 ± 0.13 seconds; $P < 0.01$). The number of cardiac contractions increased from 61.4 ± 3.39 to 80.85 ± 5.9 per minute ($P < 0.05$). The data of the PKG indicated an increased venous influx of blood to the heart (the P spike in the second lead increased from 1.05 ± 0.2 to 1.66 ± 0.2 mm; $P < 0.05$), and there was an increase in the volumetric rate of evacuation of the ventricles (the minute phases of isometric pressure increased by 161%, the period of expulsion — by 130.6%; the minute phases of passive filling of the ventricles, on the other hand, decreased to 83% of the control level). Hence, in hyperthermia instrumental investigation indicated hyperfunction of the heart, while in dehydration it indicated hypofunction.

The size of the heart in direct projection in both groups decreased in comparison with the control: lateral from 153 ± 0.13 to 139 ± 0.01 mm in the first group, and to 139 ± 0.13 mm in the second group ($P < 0.01$), while the lengthwise measurement decreased from 165 ± 0.015 to 156 ± 0.13 mm in the first group and to 152 ± 0.25 mm in the second group ($P < 0.01$). A decrease in the dimensions of the heart in both groups, apparently, was linked to a decrease in the residual blood in the ventricles, but the causes for the latter are varied. In the first group this is explained by dehydration and by a decrease in the volume of the intravascular fluid, while in the second group primary significance attaches to hyperfunction of the heart, tachycardia, decrease in the duration of diastole and increase in ventricular tonus. /30

Saturation of the arterial blood with oxygen in the first group, in dehydration, decreased by 4.2% in comparison with the control condition, while saturation of the venous blood decreased by 6.7%, therefore the arterial venous difference with respect to oxygen decreased from 25.9 to 28.4%. The difference in PO_2 in the arterial and venous blood decreased from 37.9 mm in the control condition to 26.5 mm after dehydration, i.e., by 11.3 mm. In the second group, in hyperthermia, saturation of the arterial blood with oxygen decreased by 3.6%, but the venous increased by 16.7%, and therefore the arterial venous difference with respect to oxygen in the second group fell to 6% as a result of venous hyperoxia. The PO_2 difference in the arterial and venous blood decreased even more than in the first group: from 37.9 mm in the control condition to 16.7 mm in hyperthermia, i.e., by 21.2 mm.

Consequently, in the original condition, PO_2 of the blood in the lungs of healthy people increased by 39.7 mm, while saturation of the blood with oxygen increased by 25.8%. In dehydration, PO_2 increased less, by 26.5 mm, but saturation as the result of more complete desaturation of hemoglobin increased more — by 28.4%. In hyperthermia, PO_2 of the blood circulating in the lungs increased less than in the norm or in dehydration — by 16.7 mm, while saturation by a total of 6%.

Saturation of the blood with oxygen slightly diminishes both in dehydration and in hyperthermia. In the first group this can be related to the result of hypofunctioning of the heart and slowing of the pulmonary circulation, and in the second group, taking into account hyperfunction of the heart, accelerated blood flow and hyperventilation, one should apparently seek the cause in hypocapnia. Thus, PCO_2 of the arterial blood in hyperthermia decreased from 42.42 ± 0.58 mm in the control condition to 34.2 ± 1.32 mm ($P < 0.01$). Change in PCO_2 in the arterial blood in dehydration was statistically unreliable.

Reduction of HBO_2 increases in the first group and decreases in the second group. The latter is partially explained by hypocapnia in hyperthermia. Thus, the control PCO_2 in the venous blood was 53.7 ± 1.83 mm, and in dehydration decreased to 44.0 ± 1.30 mm, while in hyperthermia it decreased even more, to 39.5 ± 1.26 mm ($P < 0.01$). This permits one to consider that the reason for

a worsening in the subjective condition during hyperthermia is not arterial hypoxemia, but rather tissue hypoxia. Similar data have been obtained in an experiment performed on 8 dogs by Frankel et al.

With respect to the condition of the acid-base balance, it should be noted that in dehydration or hyperthermia of healthy people, the change in pH of the arterial blood was statistically unreliable. In the venous blood, in the second group, pH increased from 7.29 ± 0.006 to 7.38 ± 0.006 ($P < 0.02$), and there was a compensative increase in the base deficit, from -2.46 ± 0.32 to -4.0 ± 0.67 meq/l ($P < 0.05$). The difference of these indices from the control level in the first group was statistically unreliable.

Investigation showed a worsening in the subjective condition of healthy people in hyperthermia which was directly related to tissue hypoxia. In hyperthermia, hyperfunction and decrease in size of the heart were observed, as well as accelerated blood flow, increase in pH and venous blood pressure, with an increase in protein content, increase in specific gravity and viscosity of blood, decrease in content of potassium and chlorine in the plasma, and decrease in the arterial venous difference with respect to oxygen as a result of disorders of HBO_2 dissociation; venous hyperoxia appeared. The change in these indices, as well as the condition of the coagulating system of the blood did not exceed the limits of physiological fluctuations. Restoration of body temperature to the norm was accompanied by an improvement in subjective condition, and by return of the indices of circulation and hemoglobin dissociation to the control level.

Dehydration of healthy persons was accompanied by loss of electrolytes, /31
primarily chlorine and potassium, with the urine, and with maintenance of a stable balance of potassium and sodium in the plasma and erythrocytes. Dehydration within limits of 3 to 4% of the body weight was not reflected in the subjective condition and was characterized by hypofunction of the heart, decrease in the residual blood and size of the heart, and slowing of blood flow; there was a decrease in PCO_2 and pressure of the venous and arterial blood. An increase in protein content, specific gravity, viscosity, and pH of the blood was noted; coagulation activity of the blood decreased. The obtained data are within the limits of physiological fluctuations.

The data of complex instrumental investigation of healthy persons in physiological dehydration and hyperthermia are a basis for revealing disorders of homeostasis and objective estimation of changes in the water salt metabolism, the condition of the acid-base balance and gases of the blood in infectious diseases, specifically in diseases of the gastrointestinal tract.

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16. Abstract

Clinico-physiological and biochemical changes of homeostasis in 16 healthy males undergoing dehydration of up to 3-4% of the body weight and in 8 normal males in whom the body temperature was raised to 38.1--40.3% were analyzed. Changes occurring in the physical and chemical properties of the blood, such as in its specific weight, viscosity, hematocrit (D.C.V.), protein, blood clotting system, acid-base balance, electrolytes and gas movement are described. Differences in the contractile activity and size of the heart, the state of the peripheral circulation following dehydration and hyperthermia and, in particular, the emergence of venous hyperoxemia in the lastly names cases were disclosed. Changes in the homeostasis following physiological dehydration were investigated with a view to giving substance to the method of water and electrolyte therapy used in treating dehydrated patients with acute gastrointestinal infections. Variations in hyperthermia are of interest in appraising the effect of therapy accorded to febrile infectious patients.

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